Positron Accumulator Ring (PAR) RF System Design and Test*

Jeffrey D. Stepp, James F. Bridges
Argonne National Laboratory
9700 S. Cass Ave., Argonne, IL 60439 USA

Abstract

We describe the rf system of the positron accumulator ring (PAR) of the 7-GeV Advanced Photon Source. Two rf systems are described: a fundamental frequency system at 9.8 MHz, and a twelfth harmonic system at 117.3 MHz. A block diagram of an accelerating unit is shown and descriptions of various amplifier subsystems are given (including amplifier design, power coupling, VSWR protection, and cavity tuning control). We describe beam accumulation of 24 macropulses from the linac and the 9.8-MHz system used to both accumulate and bunch the beam during the 400-mS injection time. Further bunching of the beam is done during the 100-mS bunching time by the twelfth harmonic system, so that the bunch fits in the 352-MHz bucket in the booster (injector synchrotron). Both tuning angle and cavity voltage of the twelfth harmonic system are preset with a feedforward system using a signal from the beam current monitor. Control signals which synchronize PAR with the linac and booster are described. Operating experience during the PAR commissioning will also be discussed.

1. POSITRON ACCUMULATOR RING (PAR)

There are two rf systems in the PAR. One operates at 9.8 MHz to accumulate beam from the linac, and a second operates at 117 MHz for the last 100 mS of the 2-Hz injection cycle to bunch the beam until extraction. Each system consists of one cavity, one rf amplifier, and associated control circuitry (see Figure 1). The control system also synchronizes operation with the linac during injection and with the synchrotron during extraction. Control of the rf system for accelerator operation is described elsewhere.[1]

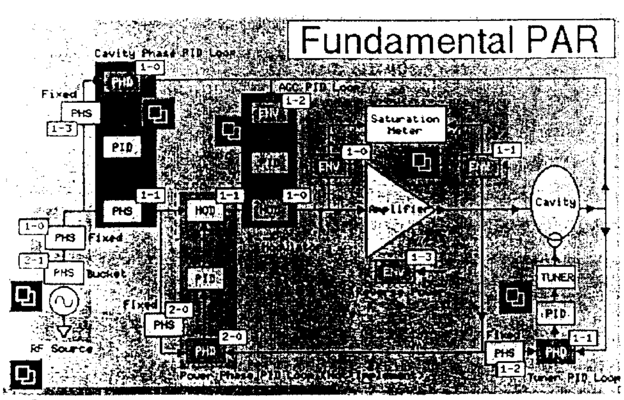

Figure 1- accelerating unit block diagram

1.1 9.8-MHz System

TABLE I. FUNDAMENTAL PARAMETER LIST

Frequency	9.77584 MHz
Harmonic Number	1
Peak Voltage	40 kV
Power	4.0 kW
Cavity Type	Cap-loaded Coaxial
Cavity Tuning	Electronic
Control Loop Bandwidth	10 kHz
Filling Time (2Q/ω)	248 μs
Phase Detector Resolution	1.0 degrees

Both cavities will have ferrite tuners. The lower frequency cavity tuner will have a range of about two bandwidths or about 4 kHz and will compensate for fast (up to 20 kHz) tuning errors due to mechanical vibrations and also for beamloading. Beam is injected at a nominal 60-Hz rate up to 24 bunches. Each bunch changes the phase angle of the generator impedance by about one degree which is easily corrected by the tuning feedback loop. A small motorized panel at the high current end will be used to tune out slow (less than one Hz) drifts in frequency due to heating. If this panel does not have enough range, the water cooling the cavity will be temperature regulated to keep the cavity at a relatively constant temperature as rf power is applied, or as the ambient temperature changes.

The ferrite cores were obtained from Fermilab. They are Toshiba type M4C21A with outer diameter of 8 inches, inner diameter of 4 inches, and a thickness of 1 inch. They were bought about twenty years ago for use in the booster and main ring synchrotrons.

The power amplifier will be four commercially bought 10MHz 1-kW solid-state amplifiers located near the cavity to minimize resonances in the transmission line. The maximum 1st-harmonic gap voltage developed by a 60mA beam is 24 kV. The present plan is to produce 40 kV, with four amplifiers plus some (slight) extra power in case one amplifier fails. The detuning angle is about 31 degrees.

*Work supported by the U. S. Department of Energy, Office of Basic Sciences, under contract W-31-109-ENG-38.

1.2 117-MHz System

TABLE II. TWELFTH HARMONIC PARAMETER LIST

Frequency	117.3101 MHz
Harmonic Number	12
Peak Voltage	30 kV
Power	1.82 kW
Cavity Type	λ/2 Coaxial
Cavity Tuning	Electronic
Control Loop Bandwidth	10 kHz
Filling Time (2Q/ω)	68 μs
Phase Detector Resolution	1.0 degrees

Four 500-W solid-state amplifiers for 117 MHz are mounted near the cavity to make a 2-kW amplifier as the rf power source, to produce a 30-kV accelerating voltage, and the cavity is powered via coaxial cable to minimize phase delay at 117-MHz.[2]

The cavity is a one-half wavelength coaxial design with a Q about 2500, so the time constant is about 7 μs. Resistive loading is included using a stainless steel shell. Otherwise, the beam induced voltage would be four times higher than the generator voltage. Using stainless steel lowers the beam voltage to about the generator voltage, considerably easing the requirements of the tuning feedback loop. This keeps the detuning angle with maximum beam loading to about 40 degrees.

1.3 Tuners

The higher frequency cavity, used for bunching the beam to fit the 352-MHz bucket in the booster synchrotron, will have a wider tuning range, perhaps up to 250 kHz. Then the cavity can be de-tuned to a low impedance during the accumulation time, yet be tuned in about 10 ms for adiabatic capture of the beam at the beginning of the 100 ms bunching period. Another approach is to use this cavity to damp the beam during accumulation; a tuning range of only several bandwidths (47 kHz) would be enough. The ferrite tuner will also cancel any slow frequency drift; since this cavity is powered for only 20% of the time, drift due to heating the stainless steel will probably be small compared to a bandwidth.

A voltage proportional to the peak current injected into PAR is used to pre-set the rf drive level and tuning before turn-on. The ICT (integrated current monitor) gives the integrated charge and is updated after each injected beam pulse.

2. AMPLIFIER DESIGN CONSIDERATIONS

2.1 Power combining

The cavity is used as a narrowband combiner at the fundamental frequency. Four amplifiers are mounted near the cavity with 50-V DC power supplies in a rack in the electronics room. The commercial amplifiers have an octave bandwidth from 2 - 30 MHz and have higher harmonic content at the low-end operating frequency. To minimize the rf voltage on the drain of the FETs due to reflected power from the cavity, an in-line lowpass 12-MHz filter was added in parallel with a 25-MHz highpass filter to absorb the harmonic power output of the amplifier. See Figure 2 for a picture of the amplifier distortion on the drain of the FET. The return loss into the cavity is better than 13 dB.

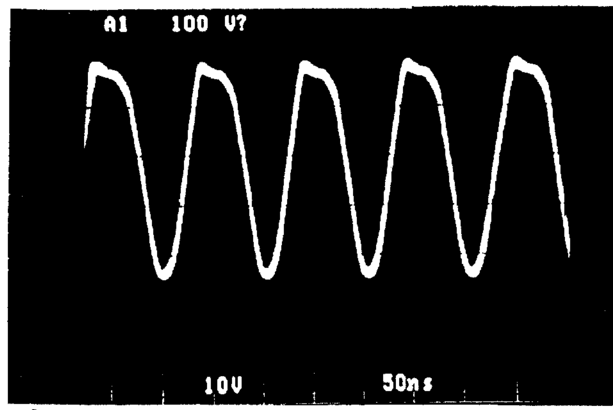

Figure 2 Amplifier drain distortion

2.2 Drive Power

Rise time of the rf envelope will be ramped slower than the cavity filling time to avoid amplifier mismatch.

3. CAVITY COUPLING CONSIDERATIONS

3.1 Loop coupling

The coupling loops are sized to have a resistance magnitude of 12.5 ohms, woth some nominal amount of inductance at the fundamental frequency.

3.2 Stripline coupling

To reduce the reflected power due to the 3rd harmonic output from the amplifier, a stripline coupler was put into the cavity. The inductance at 30 MHz was reduced by one half but this was not enough to warrant its use, since it was difficult to adjust in the available space.

4. AMPLIFIER PROTECTION CONSIDERATIONS

4.1 Tuner Feedback

A feedback system is utilized to monitor the phase difference in the cavity and adjust the tuner to keep the cavity at the resonant frequency within +/- 1.0° under beam loading and rf heating.

The ferrite tuner has a frequency tuning range of 10 kHz to compensate for beam loading, temperature effects, etc. The feedback loop that drives the tuning works only on the reactive element of the cavity input impedance. A high quality (Techron model 7570) audio amplifier (2 kW @ 100v/20A) drives the tuner bias winding with a bandwidth of DC to 50 kHz.

4.2 VSWR Protection

The breakdown voltage of the FET drain to source is 125 V. With a maximum of 50 V bias DC supply voltage, the limit of rf output power and the maximum reflected rf power from the cavity is determined. A compromise is set between the available power from the amplifiers and the allowable reflected power from the cavity before turning down the rf power. See

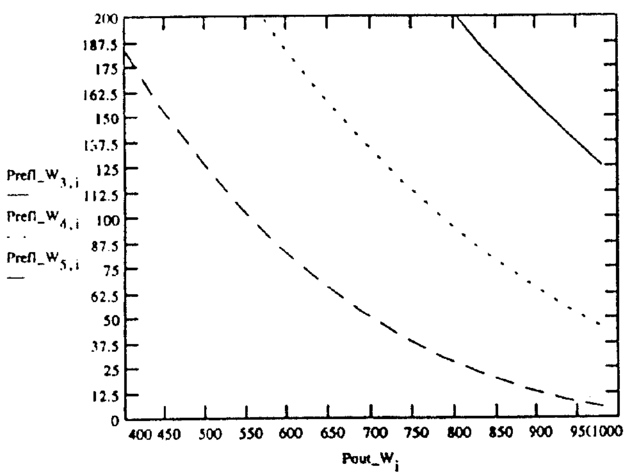

Figure 3 Maximum reflected power vs. output power

Figure 3 for a curve of allowable reflected power to output power for 30, 40, and 50 VDC.

5. OPERATING EXPERIENCE

Beam accumulation is done regularly for PAR accelerator physics studies. The harmonic system has not been used because synchrotron commissioning has just started. It will be tested in the June/July commissioning time period.

The stored current in the ring varies from 3 to 9 mA depending on the particular accelerator experiment. A maximum of 60 mA has been accumulated; 56 mA average is the design current for the PAR. Typical beam loading for 19-mA stored current and a gap voltage of 12 kV detunes the cavity by 18 degrees. The gap voltage setting varies from 8 kV to 31 kV for studies as a function of stored beam energy from 250 MeV to 375 MeV.

The center conductor is water-cooled and is held at a constant 32 degrees C due to the water temperature, but the outer conductor expands from both rf heating and the rise in ambient air temperature as the non air-conditioned room heats from 28 degrees C at startup to about 38 degrees C after a few hours. This detunes the cavity approximately 10 kHz.

The tuning loop has a maximum gain limit of 2, while the AGC loop has a gain limit of 7.

6. REFERENCES

1. J. Bridges, J.Stepp, "General Overview of the APS Low-Level RF Control System," Proceedings of the 1993 Particle Accelerator Conference, Washington, D.C., 1993.

2. D. Boussard, "Control of Cavities with High Beam Loading," IEEE NS-32, No. 5 (Oct. 1985).